On division N disappears and

$$\frac{K-1}{4\pi c^2 k} = 2\frac{\delta l_0}{r^2\theta_0},$$

so that the optical rotation per unit depth is

$$p^2\frac{K-1}{8c^2}\frac{r^2\theta_0}{\delta l_0}, \quad \text{or} \quad \frac{\pi^2}{2\lambda^2}(K-1)\, r\,\frac{r\theta_0}{\delta l_0}.$$

If r is of the order of the diameter of a molecule, say 10^{-8}, this reduces to the order of $10r\theta_0/\delta l_0$ for visible light.

Actually the optical rotation is of the order of two right angles per centimetre for quartz, and seems to range to several times less for pure active liquids. This indicates that the angle of pitch of the relative screw displacement of the positive and negative components of the structures should range around $\frac{1}{10}$, so that the chiral element may twist under an electric field about one-tenth as much as it elongates. This indication is extremely rough; but bearing in mind that powers of the velocity of radiation are involved in the estimate, one may claim that it does not detract from, but rather substantially supports, the type of picture of the phenomena which has been under review.

The Colour of the Light from the Night Sky.

By Lord Rayleigh, F.R.S.

(Received February 7, 1921.)

The general light of the sky at night is very faint, and beyond the observations of Campbell* and Slipher,† who could always detect the aurora spectrum line in temperate latitudes, nothing appears to be known of its spectroscopic or chromatic character. Slipher, indeed, suggested that the variability in its brightness recorded by Yntema might be accounted for by attributing the light mainly to a variable aurora. But this view has been controverted, rightly as I think, by Fabry.‡ My own observations, now to be recorded, indicate that at the time and place where I was working little, if any, of the light could be attributed to the green aurora line.

The great difficulty of spectroscopic observations is, of course, the want of light; though if the light were monochromatic, as, for instance, if it were all

* 'Astr. Soc. Pacific.,' vol. 29, p. 218 (1917).
† 'Astr. Jour.,' vol. 49, p. 266 (1919).
‡ 'Astr. Jour.,' vol. 50, p. 308 (1919).

concentrated in the aurora line, this difficulty would be much mitigated. I thought it worth while, however, to try if anything could be learnt by a cruder method, which possesses some advantages even if the light is not very feeble.

A series of small coloured filters were arranged so as each to transmit a limited portion of the spectrum. These were placed in a suitable frame, which held in addition a neutral-tinted photometric wedge of carbon in gelatine, made by Mr. Sanger-Shepherd. This wedge was graduated in equal parts, according to Hunter and Driffield's method. (Scale-reading 10, light transmitted = 1/10; scale reading 20, light transmitted = 1/100.) A photographic plate was placed in the frame, so that part of it was under the various colour filters and another part under the wedge. This could be exposed to the night sky or other source of light.

After development, the photographic intensity under each coloured screen will match the intensity under some point on the wedge. The plate, therefore, gives a record of what fraction of the total photographic effect due to the source is transmitted by each screen. For comparable results with different sources of light, it is of course necessary to keep to the same kind of photographic plate.

The great advantage of the method is that it allows light to be used from a cone of very large angular aperture. With a spectroscope we cannot, under the most favourable circumstance, use an aperture ratio of more than 1 : 2. But a plate under the coloured filters may be exposed to the entire hemisphere if desired. Moreover, when faint impressions are concerned, a large patch of defined shape and uniform, even if small, intensity practically gives much more confidence to the experimenter than a small and faint spectrum. The information given is of course of a rather different kind.

Coming now to details. The coloured screens were :—

	Transmission.
1. Ultra-violet glass, supplied by Messrs. Chance	3300–3800
2. Cobalt blue glass. Several thicknesses	4000–4500
3. Bluish-green glass	4300–5300
4. Green glass	5100–5900
5. Flavazine	5500–7000
6. Flavazine, with didymium glass	5500–5630 and 5930–7000
7. Wratten's red filter, No. 23A	5800–7000

These were chosen, so far as possible, to give nearly the same photographic density with sunlight. This is desirable, because the range of intensities which the plate can deal with is not unlimited. The green and red filters,

which transmit portions of the spectrum to which the plate is comparatively insensitive, were chosen to give as large transmission as was consistent with isolating a fairly narrow range of the spectrum.

Filter No. 6 was designed to isolate as nearly as possible the green aurora line, if present. No filter could be found to cut out the red without at the same time involving serious loss of green.

Ilford special rapid panchromatic plates were used. These were far more effective in the red, yellow, and green regions than any other plates I have tried. All the results recorded were obtained with a consignment of plates bearing the same number, and therefore, presumably, as nearly alike as may be.

An ink mark on the under face of the wedge gave a fiducial mark on the negative, and starting from this, the wedge scale was copied by hand on to the developed film, marking it on with a fine pen.

The photometric work on the developed plates was done with the photo-electric apparatus described in connection with the scattering of light by gases.* Briefly, it depends on a photo-electric cell with battery and galvanometer. The plate rests on a table, in which is a slit. Above is a bright light focussed on the slit with a lens. The rays diverging beyond the focus fall on the photo-electric cell. The deflection of the galvanometer depends on the opacity of the photographic film. The impression through a colour filter was placed on the slit, film downwards, and the deflection noted. The impression of the wedge was then substituted, with the length of the slit at right angles to the length of the wedge. The plate was then slid along until the previous deflection was recovered, and the position of the slit on the wedge scale noted.

On a given negative, the result was usually recovered to within about 0·2 of a scale division, but, with another negative, discrepancies as large as 1 scale division (representing a factor of 1·26), or even more, were observed. These are due either to inequalities in the photographic film† or to changes in the quality of light received from the source, due to varying atmospheric conditions.

The photo-electric measurement of a given negative was very satisfactory, and far preferable to visual photometry.‡

The first series of experiments was made with the plate exposed to the entire sky, so far as it was not blocked out by trees and buildings. This

* 'Roy. Soc. Proc.,' A, vol. 97, p. 440 (1920).

† See the remarks in my paper, *loc. cit.*, p. 442. The plates used in the present work were coated on common glass, not plate glass.

‡ The latter can, no doubt, be applied to smaller areas on the negative, which is important in some investigations.

method is open to the objection that some of the rays pass very obliquely through the coloured screens, with the result that the effective thickness of the latter becomes somewhat indefinite. This, however, does not seem to vitiate the result appreciably, as subsequent experience showed; while an important advantage is gained in shortening the exposure.

Comparison of the night sky with the clear twilight sky (Table I) shows clearly how much poorer the latter is in yellow and red light. The wedge readings for the two yellow and the red filter differ by about 4 scale divisions, showing that, for the night sky, the yellow and red components account for 2·5 times as large a percentage of the whole photographic effect as in the twilight sky.

Table I.—The Figures given are the Wedge Readings, obtained as described.

	Starlight sky.		Twilight, clear sky. August 17.
	August 9.	September 6–7.	
Ultra-violet glass	10·6	10·0	9·9
Cobalt glass	13·1	13·3	12·4
Bluish-green	12·5	12·2	11·3
Green	14·7	13·7	16·1
Flavazine	8·5	8·0	13·1
Flavazine with didymium	12·1	10·9	16·1
Red	10 7	10·0	15·0

The next series of experiments were designed to include in the comparison the direct light of the sun and moon. These give approximately parallel rays, which traverse the absorbing screens normally. For comparison with them, it is desirable to restrict the cone of rays from the night (or day) sky as far as other conditions will allow. An aperture, 15 inches in diameter, was placed 15 inches from the plate. This aperture was the smallest that could well be used. The work was carried out in August and September and early October, when the hours of complete darkness are very limited. Summer time imposes a further obstacle. The moon must be below the horizon and the night should be clear. With the aperture ratio 1 : 1, as described, about nine hours' exposure were needed to give satisfactory intensity.

Two plates with this exposure were all I could get before my enforced return to London in October. The exposures were made at Beaufront Castle, 3 miles from Hexham, Northumberland, and also at Terling Place, Essex. There was no appreciable interference from town light, diffused by the sky.

In making exposures to direct sunlight, the difficulty was to reduce the

photographic effect sufficiently. The ideal method would be to use a pinhole camera, giving an image of the sun which would cover the quarter plate used, but this involves an impractically long camera. To work at a reasonable distance, more divergence of the rays is essential. It was got by means of a quartz lens, of 7 mm. diameter and 9 mm. focus. The plate was placed on the axis of the lens, at about 60 cm. distance, when the divergent cone of rays from the image covered an area more than large enough. The lens was mounted in the end of a blackened box, with a kodak photographic shutter over it. The plate holder, carrying the coloured screens and photometric wedge, was introduced at the other end of the box. A simple shadow arrangement was provided for pointing the axis of the lens at the sun.

A quartz lens was used, so as to avoid any absorption of ultra-violet light, or any risk of introducing colour which might disturb the comparison of sunlight with other sources.

Exposures were also made on direct moonlight. For these no special arrangements were needed, as an exposure of several seconds proved suitable.

The results are given in Table II.

Table II.

	Starlight sky.			Blue sky at sunset.		Blue sky, Sept. 24, 1 p.m.
	Sept. 15–16.	Oct. 8, 9, 10.	Mean.	Sept. 27.	Sept. 28.	
Ultra-violet glass	13·2	11·9	12·6	12·3	15·4	10·4
Cobalt glass	14·9	14·8	14·8	13·5	12·8	14·0
Bluish-green	11·8	12·3	12·0	11·9	13·3	12·8
Green	13·5	14·7	14·1	16·3	17·2	17·6
Flavazine	8·5	8·5	8·5	12·9	15·1	13·9
Flavazine with didymium	11·5	11·6	11·0	16·6	17·0	18·0
Red	9·9	11·9	10·9	14·3	16·2	16·3

	Sun, 33° up.			Moon, Sept. 26, 33° up.		Basalt, fresh.	Basalt, weathered.
	Sept. 22.	Sept. 28.	Sept. 28.				
Ultra-violet glass	14·9	15·8	14·9	14·9	15·0	14·9	16·2
Cobalt glass	14·3	15·2	14·6	15·2	15·0	14·4	15·6
Bluish-green	11·7	12·9	13·2	11·4	12·0	11·3	11·5
Green	13·2	14·1	15·5	14·0	14·2	13·1	12·3
Flavazine	7·0	8·0	8·8	7·5	7·4	7·8	5·5
Flavazine with didymium	10·7	11·0	12·2	11·3	10·7	10·6	8·8
Red	9·0	10·8	11·5	9·5	8·7	9·3	7·4

In considering these results, it will be noticed in the first place that the wedge readings for cobalt glass and bluish-green glass respectively are nearly the same whatever the source of light. This merely expresses the fact that by far the greater part of the photographic effect of the spectrum is due to the kind of light which these glasses can transmit. In any case the ultra-violet or red ends of the spectrum produce a comparatively small fraction of the whole effect, consequently the absence or presence of these constituents hardly affects the wedge reading for the blue.

It is in the case of the ultra-violet at one end of the spectrum and the yellow and red at the other that enough variability is to be expected to give information as to the constitution of the source.

The ultra-violet constituent tends to be variable for plates obtained on different occasions. This is not surprising when we consider that this constituent is largely affected by atmospheric absorption, and is therefore sensitive to atmospheric conditions, even when the sky is apparently clear. For the same reason this constituent will be largely affected by the altitude of the source. Thus the sun and moon, both exposed to at 33° altitude, are at a disadvantage compared with the zenith sky.

For these reasons not much can be inferred from the ultra-violet data. It is noteworthy, however, that the zenith sky seems much richer in this constituent when the sun is high, than at sunset. This may be accounted for by atmospheric absorption of the rays from the low sun before they reach the observer's zenith, and are scattered towards him by the air.

The great superiority of the night sky over the day sky in yellow and red light is again apparent, amounting as before to about 4 scale divisions (a factor of 2·5).

The night sky also differs very little in quality from direct sunlight. It is only in the ultra-violet that any definite distinction is apparent, and as already remarked, the zenith sky would have an advantage in this region on account of less atmospheric absorption.

No definite distinction can be made from these experiments between the chromatic constitution of sunlight and that of moonlight. The numbers found are the same within the limits of experimental error.

We may say therefore that the night sky is found to be of the same colour as direct sunlight or moonlight, but much yellower than the clear day sky.

Colour of Moonlight.

What we can see of the moon's surface suggests that it consists of volcanic rock, and the light is, of course, diffusely reflected sunlight. It occurred to me, in connection with the present experiments, to include in the comparison

sunlight diffused from specimens of terrestrial volcanic rock. These exposures were made when the sun was 33° up, so that atmospheric absorption should be as nearly as possible the same as when the moonlight exposures were made. The photographic plate was placed in the box used for exposures to direct sunlight, but the quartz lens was removed. The iris diaphragm attached to the shutter was adjusted so as to subtend half a degree at the photographic plate—the same angular diameter as the moon—and it was backed with the specimen of rock in full sunlight placed near the aperture. The same exposure was given as was given to direct moonlight. Only two exposures were made, one to a specimen of fresh basalt, and another to a weathered ochreous surface of the same. The light from the fresh basalt cannot be distinguished definitely in quality from moonlight or sunlight, but the light from the weathered basalt appears to be distinctly yellower than moonlight. The experiments are too few for a final conclusion, but they suggest that the surface of the moon is more like the fresh than the weathered specimen. This is in accordance with the absence of a lunar atmosphere.*

Visual Observations on the Night Sky.

The conclusions reached, photographically, on the night sky are entirely confirmed by visual observation.

The photometric comparison of lights of different colours is, under ordinary circumstances, difficult and embarrassing, and little definite significance attaches to the results. But with lights below a certain intensity this difficulty disappears, since there is no longer the power of colour discrimination, and vision is monochromatic. A confident decision can then be given as to which of two lights appears brighter, whether they are of the same spectral quality or not. This is, of course, well known, and is fully elaborated in works on colour vision.

Two gelatine films on glass were prepared, one dyed yellow with flavazine, and the other with methylene blue, the intensity of the latter being adjusted by washing out some of the colour until right for getting the effects which will now be described. The two films were mounted edge to edge at the end of a pasteboard tube, so that, when the tube was directed to the sky, the circular field was seen divided into two along a diameter.

During the daytime the yellow film was considered by all observers to be the brighter. As twilight advanced, the Purkinje phenomonon came into evidence, and the blue film became brighter. This remained the case when

* These experiments on rock were hampered by the fact that the photometric apparatus was not at hand when the exposures were made. They are merely of a preliminary character.

the light had waned so far that the colour sensation had disappeared. As the stars came out, the predominance became less marked, and, before the Milky Way was distinguished, there was equality. Finally, when the Milky Way was conspicuous, the yellow film was notably brighter, whether the tube was pointed to the Milky Way or to other parts of the sky.

Another pair of films was prepared, giving equal intensities when the night sky was viewed. In this case, still more than in the previous one, the blue half appeared brighter while any twilight remained.*

It was desired to confirm visually the conclusion reached by photography that the colour of the night sky was nearly the same as that of direct sunlight or moonlight. Moonlight was chosen, as being of more convenient intensity. It was found that the yellow and blue films, which appeared equally bright against the night sky, also appeared equally bright when viewed against a white cloth exposed to direct moonlight. This background was, however, somewhat too bright, and, in order to get rid of colour perception, it was found advisable to reduce it twelve-fold by means of Fox Talbot's revolving sector. It was then impossible to distinguish between the two coloured films, which appeared of exactly equal intensity.

The night sky was examined on many occasions through the pair of films, which gave equal brightness. I never observed any marked deviation from equality, at considerable altitudes, though low down the yellow often had an advantage. This is probably attributable to selective atmospheric absorption. The experiments gave no evidence of a variable colour such as might be produced by an aurora of variable intensity.

I may add that my own attempts to see or photograph the aurora line on ordinary nights have had no success. All that I could see was a continuous spectrum.

[*Note added, March* 4.—I have since succeeded in regularly photographing the aurora line.]

Summary and Conclusion.

To get information as to the chromatic character of the light from the sky at night, photographic exposures were made under coloured media selected for isolating various parts of the spectrum. By comparing the photographic densities obtained, it was concluded that the night sky was much yellower or less blue than the (clear) day sky. Comparison with direct sunlight or moonlight showed that the night sky was of the same quality as these.

Visual comparisons through coloured films showed that a blue film, which

* A preliminary notice of this result was published in a letter to 'Nature,' dated August 20, 1920.

was equally bright with a yellow one against the night sky, was brighter against the twilight sky. These comparisons were not embarrassed by colour differences, because the light was so faint as to give purely monochromatic vision. The two films matched one another equally well, whether they were seen against the Milky Way or against other parts of the sky. In the photographic work no special attention was paid to this point, the exposures being made to a considerable area of sky around the zenith. The diurnal motion, of course, brought successive areas of the sky into action during the long exposures.

One theory of the light of the night sky attributes it to sunlight scattered by a very rare gaseous atmosphere, situated so high up as to be outside the earth's shadow. The present observations are contradictory of this theory, which would require the night sky to have the same colour as the day sky.

The comparative absence of polarisation* leads to the same conclusion.

The requirements, as regards colour and polarisation of the light, would be satisfied if we regarded it as coming from an unresolved background of stars. They would equally be satisfied if we regarded it as due to sunlight scattered by meteoric matter. The conclusions of van Rhyn† favour the latter alternative. He regards the general light of the sky as an extension of the zodiacal light.

* See Rayleigh, 'Astr. Jour.,' vol. 50, p. 227 (1919); also Babcock, *ibid.*, p. 228.

† 'Astro. Phys. Jour.,' vol. 50, p. 356 (1919).